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A THEORETICAL STUDY OF THE PROPAGATION AND ATTENUATION OF ACOUSTIC WAVES IN THE LUNAR SURFACE

Interim...

Interim Report

TM-1325

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SUMMARY

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Computations were made of the decrease in displacement of waves with frequencies from 25 to 3500 cps in passing through an attenuating medium. The usual attenuation equations were used with constants which have been determined by seismological experiments. Calculations were made at 2-ft intervals for 2 to 20 ft of wave travel. Author

INTRODUCTION

To help resolve some of the problems concerning the accuracy of the devices for measuring sonic velocity in the lunar surface Texaco Experiment Incorporated has made a short mathematical study as a part of contract No. 950155 of the attenuation of sonic waves in solid media. This study can serve as a starting point for a more complete study if such a study should be required.

STATEMENT OF THE PROBLEM

The over-all problem is to determine theoretically the output of a transducer as a function of (a) the amount and type of explosive used to generate a gas wave which will strike the lunar surface and start a surface wave which will activate the transducer and (b) the distance of the transducer from the explosive source. Some of the factors which must be included in a complete study are listed below.

A. The effect on the gas wave of:

1. Type of explosive
2. Amount of explosive
3. Shape of the explosive charge
4. Geometry of the source holder
5. The near-zero ambient pressure of the lunar surface

B. The effect on the coupling of the gas wave to the lunar surface of:

1. Velocity of the gas wave
2. Pressure across the gas wave
3. Duration of pressure pulse from wave
4. Surface area contacted by the gas wave
5. Type of surface (degree of roughness)
6. Type of material in the surface (loose or compacted)

C. The effect on attenuation of the initial surface wave of:

1. Type of surface material
2. Horizontal uniformity of the surface
3. Vertical uniformity near the surface
4. Harmonic composition of the surface wave

D. The effect on the coupling of the transducer to the surface wave of:

1. Type of surface
2. Type of material in surface
3. Harmonic composition of surface wave

E. The effect on the response of the transducer of:

1. Harmonic content of the coupled wave
2. Type of transducer (geophone or accelerometer)
3. Mechanical and electrical noise level

If information on all of these factors were available, it should then be possible to work from the required transducer output back to the required source or from a source to the output of the transducer. One of the difficult steps in the middle is the determination of the amplitude and phase relationship of the various frequencies in the wave that is formed in the surface. The factors included in A and B above must be coordinated in such a way as to permit this determination.

There is obviously no theoretical solution to most of these factors. This means that empirical information from many sources will have to be used. To make a complete study, part of the necessary empirical information will probably have to be obtained by experimentation.

APPROACH

From the previous statement of the complete problem it is obvious that only a small start could be made in the three weeks alloted to the present study. Therefore, it was necessary to select those factors which would yield the most useful information in the time alloted.

To determine the velocity of the surface wave, one must measure the time it takes the wave to travel a given distance. To make an accurate determination when, as in this case, the travel distance is small, a very accurate measurement of the elapsed time is required.

As a basis for the present study it was assumed that the elapsed time would be determined by noting the time at which the wave arrived at two transducers a known distance apart. With this method the accuracy of the measurement is a function of the rate of rise of the output of the transducer as the front of the wave passes under it. This rate of rise is a function of the frequencies present in the wave, their phase relation, and their amplitude.

It is known that most formations rapidly attenuate the high-frequency components of the wave. Also it is known that high frequencies are required for fast rise time; i.e., a 25-cps wave takes 1 msec to rise to only 10% of its maximum amplitude, while the equivalent time for a 2500-cps wave is 0.01 msec. It was decided, therefore, that the first step in the study should be to determine the attenuation of selected frequencies at various distances from the source of the wave.

In accordance with the above approach the attenuation was calculated by the following equation (1):

$$I_r = I_0 e^{-kx}$$

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(1) C. A. Heiland, Geophysical Exploration, p. 480, New York, Prentice-Hall, Inc, 1946.

where

I_r = displacement at distance x

I_0 = initial displacement

k = attenuation constant (0.0049 at 25 cps and varied as the square and the 3/2 power of the frequency, f)

x = distance from initial pulse

I_r was calculated at 2-ft intervals from 2 to 20 ft for frequencies of 25 to 3600 cps with an attenuation constant, k, varying with both f^2 and $f^{3/2}$. Excerpts of the results of these calculations are given in Tables I and II.

Calculation of an actual wave form at a known distance from the source requires knowledge of the frequencies present in the initial wave, the phase relationship of these frequencies, and the displacement for each frequency. Also it is necessary to know the velocity of the wave in the media and the exact distance. These latter items are needed to calculate the phase relationship of the various frequencies at the desired distance from the source. Because the information required is not readily, if at all, available, it was not possible to continue the calculations to show the actual wave form that would arrive at the transducers.

TABLE I

DISPLACEMENT, I_r, AT SELECTED DISTANCES, x, WHERE I_0 IS TAKEN AS 1.0 AND k VARIES WITH f^2

Frequency, cps	Distance 2 ft	4 ft	8 ft	14 ft	20 ft
25	.99024791	.98059092	.96155854	.93370037	.90664929
50	.96155854	.92459483	.85487560	.76002891	.67570527
75	.91557810	.83828325	.70271880	.53934637	.41395577
100	.85487560	.73081229	.53408661	.33367253	.20846311
150	.70271813	.49381278	.24385106	.08461905	.02936376
200	.53408559	.28524742	.08136609	.01239584	.00188846
250	.37531127	.14085855	.01984113	.00104892	.00005545
300	.24385059	.05946311	.00353586	.00005127	.00000074
400	.08136593	.00662041	.00004383	.00000002	-
500	.01984111	.00039367	.00000015	-	-
600	.00353586	.00001250	-	-	-
700	.00046050	.00000021	-	-	-
800	.00004383	-	-	-	-
900	.00000305	-	-	-	-
1000	.00000015	-	-	-	-

TABLE II

DISPLACEMENT, I_r, AT SELECTED DISTANCES, x, WHERE I_0 IS TAKEN AS 1.0 AND k VARIES WITH $f^{3/2}$

Frequency, cps	Distance 2 ft	4 ft	8 ft	14 ft	20 ft
25	.9901488	.9803948	.9611739	.9330468	.9057429
50	.9723869	.9455364	.8940394	.8220045	.7557737
75	.9498588	.9022320	.8140228	.6976122	.5978489
100	.9238553	.8535089	.7284774	.5744181	.4529395
150	.8645906	.7475170	.5587817	.3611385	.2334025
200	.7993066	.6388912	.4081820	.2084463	.1064473
250	.7312029	.5346578	.2858589	.1117546	.0436897
300	.6626333	.4390828	.1927937	.0560935	.0163205
400	.5306793	.2816205	.0793101	.0118529	.0017714
500	.4125163	.1701698	.0289578	.0020328	.0001427
600	.3122370	.0974919	.0095047	.0002893	.0000088
700	.2306628	.0532053	.0028308	.0000347	.0000004
800	.1666126	.0277597	.0007706	.0000036	-
900	.1178443	.0138873	.0001929	.0000003	-
1000	.0817153	.0066774	.0000446	-	-
1100	.0556078	.0030922	.0000096	-	-
1200	.0371694	.0013816	.0000019	-	-
1300	.0244223	.0005964	.0000004	-	-
1400	.0157844	.0002491	.0000001	-	-
1500	.0100409	.0001008	-	-	-
1600	.0062901	.0000396	-	-	-
1700	.0038823	.0000151	-	-	-
1800	.0023619	.0000056	-	-	-
1900	.0014170	.0000020	-	-	-
2000	.0008386	.0000007	-	-	-

TABLE II (cont'd)

Frequency, cps	Distance 2 ft	4 ft	8 ft	14 ft	20 ft
2100	.0004897	.0000002	-	-	-
2200	.0002823	.0000001	-	-	-
2300	.0001607	-	-	-	-
2400	.0000903	-	-	-	-
2500	.0000502	-	-	-	-
2600	.0000275	-	-	-	-
2700	.0000149	-	-	-	-
2800	.0000080	-	-	-	-
2900	.0000042	-	-	-	-
3000	.0000022	-	-	-	-
3100	.0000012	-	-	-	-
3200	.0000006	-	-	-	-
3300	.0000003	-	-	-	-
3400	.0000002	-	-	-	-
3500	.0000001	-	-	-	-

DISCUSSION OF RESULTS

An inspection of the data in Tables I and II shows that especially in the high-attenuation media the high-frequency components of a wave are very rapidly attenuated to less than 10^{-9} of their original displacement. This means that unless the displacement of these high frequencies in the initial wave is of the order of 10^9 times that of the low frequencies, the high frequencies will have little or no effect on the shape of the wave at the measuring station. It seems very unlikely that this ratio of displacements will be generated in a high-attenuation medium. Therefore, the rise time of the wave at the transducer will be slow, since only low frequencies will arrive at the measuring station. Also, since accelerometers are insensitive at low frequencies, it means that they are not suited for measurements in the high-attenuation media and that a geophone should be used. In the low-attenuation media some higher frequencies are present especially at the shorter wave travels. In these cases it may be possible to obtain useful data from an accelerometer.

RECOMMENDATIONS

Since a complete study of all the factors involved in developing methods for determining transducer output as a function of the explosive source, or vise versa, is a major undertaking, it is recommended that a meeting of representatives from JPL, Texaco, and TEI be held in the near future. At this meeting JPL should explain the information they expect the study to provide and what they think should be included in the study. Texaco and TEI should present their opinion on whether a study could be made which would provide the information JPL needs and, if so, an estimate of the time and costs of the study. With this information it will then be possible to make a logical decision on how to proceed.

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